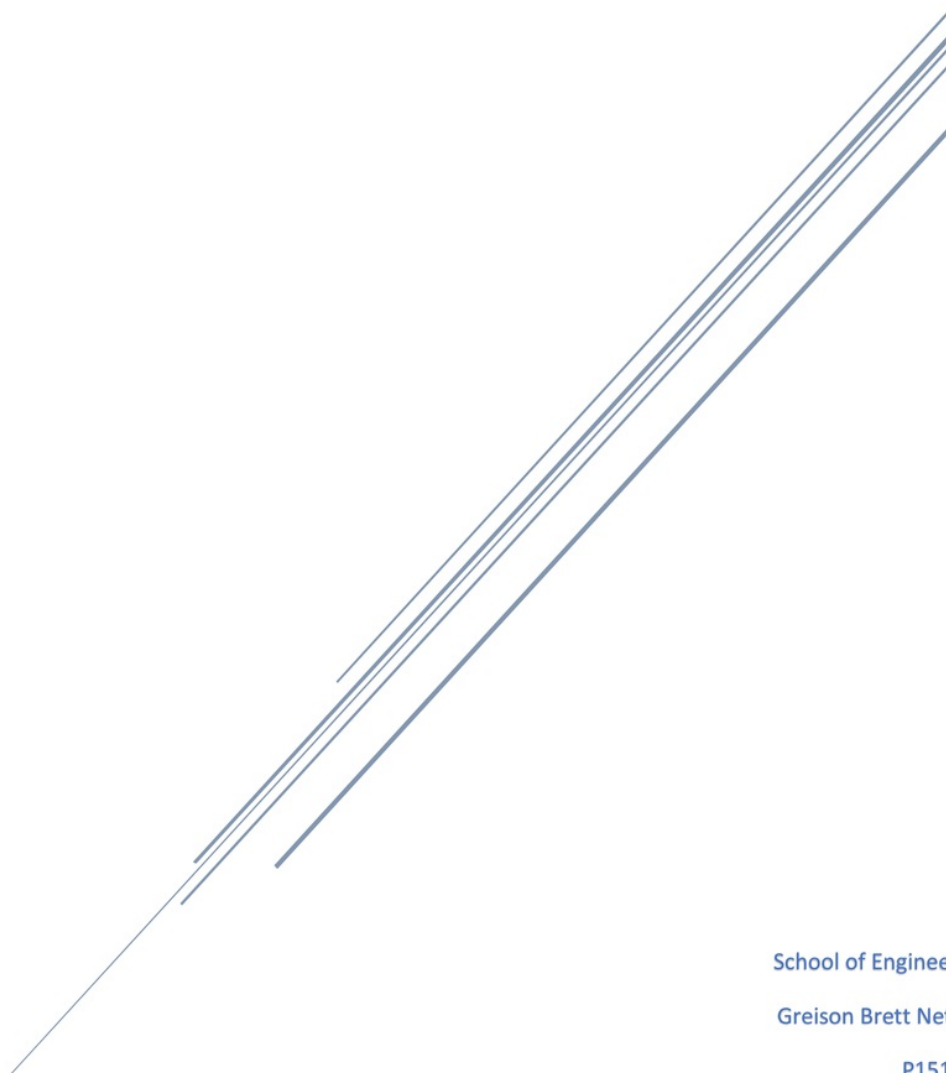


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by Greison Brett Nethell

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ANALYSIS OF DEBRIS EFFECT ON HEAT EXCHANGERS



School of Engineering

Greison Brett Nethell

P151067

Mechanical Engineering BEng

1. Abstract

An investigation into debris effects on heat exchangers by using a TecQuipment TD1007 and a 32 tube non finned heat exchanger. To do this a series of testing using varied simulated debris types was carried out. Looking at heat exchangers briefly to provide understanding on why certain results may be achieved. Analysing real world debris to then create and use simulated debris. Vehicles travelling on varying types of roads will most likely be subjected to debris, this debris can find itself on the heat exchanger of the vehicle. The aim of this investigation is to see what affect this debris, whatever size, has on the heat exchangers performance.

Firstly, by testing the TecQuipment TD1007 and using previous knowledge to help design tests and debris. The results obtained, varying with coverage, ranged from an increase of just 0.3° C with 25% coverage to 8.2°C with a full 100% coverage. Working with a vehicle engine cooling system in mind, results were compared to the effects these temperature increases might cause.

As well as basic debris coverage, insulated debris, which can also be found in real life applications, is then looked at to gain an understanding on the effects and this is also tested with a simulated insulation debris. Greater depth is then applied to further understand how the debris effects by analysing and discussing the results obtained. Along with research from similar projects to help better understand the results obtained and if other research backs up the results.

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Abbreviations

HX – Heat exchanger,

T – Temperature,

h – Hot, c – Cold

Common referrals

- TD1007 – Heat exchanger testing apparatus being used for experiments.
- Coverage/blockage – Different descriptions for Debris or foreign objects.

3. Introduction

The main aim of this dissertation is to understand to what extent does debris or coverage of a heat exchanger do to its overall efficiency. To do this, simulation tests will be run comparing an uncovered heat exchanger to a partially covered heat exchanger. The test will be done using one heat exchange, a 32-tube non-finned design.

The main idea comes from debris such leaves, dirt or rubbish that get stuck or trapped onto a HX, what effect does this have? Could it be so significant it can lead to overheating of an automobiles engine if it was in that environment?

The testing apparatus being used is the TecQuipment TD1007 water to air heat exchanger. This the university's own equipment so is always available for use. This equipment will be the main equipment in this investigation.

To simulate debris or coverage, materials such as cardboard will be used to block off a percentage of the heat exchanger, from this percentage area covered, the efficiency affected can be attributed to this coverage. To simulate insulating debris, basic modelling clay will be used in conjunction with standard debris.

In initial tests optimal flow rate will be found so that this can be a set figure and can be applied to all further tests to make tests fair, reliable and control variables in the experiment. Once tests have been carried out, results will be logged and an evaluation on efficiency effected looked at and recorded. Also, there will be a section on what could be improved about the testing, recordings and overall process.

Research will also be carried out to see what other investigations have been done and how similar they are to this one, to back up or contradict the findings in this investigation.

After results have been obtained, the discussion chapter will analyse what these results mean and what could be done, moving on to a conclusion which will summarise the results and give a final

verdict on the results.



Figure 1 – The TD1007 Testing apparatus.

4. Literature Review/Background/Research

The main reading for this dissertation will be the booklet for the heat exchanger testing apparatus, this will give most of the information needed. The other background information and research will come from classes attended on Advanced Thermofluids module (M6X02306), research online and in the library will be stated in the references page (page 24.)

Researching of similar experiments will be carried out in order to increase knowledge of the overall subject. This experiment will not be looking at flow rate and heat exchanger design in great detail only to see what happens when they change, and if the efficiency is affected.

Looking at research papers and information available on the internet, the results gained from this experiment can be compared to them to see if they back up the findings or contradict them. This will be very helpful as it will give an indication as to if the experiment carried out is matching other researchers' findings.

Moving forward from this, different coverage/debris can be looked at and possibly tested or researched. This would be mostly looking at the Porsche 911 issue, of collecting an insulating type of debris within its bumper placed heat exchangers.

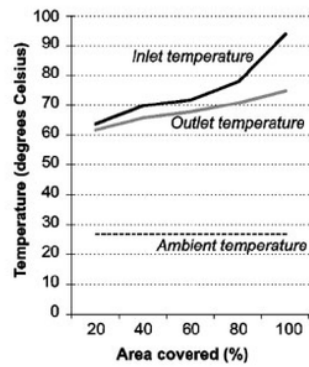
4.1 Dirt analysis on the performance of an engine cooling system

Analysis of the results showed that every 10% increase in area of coverage with silt soil resulted in an increase of about 1.7° C of the outlet temperature of the radiator coolant. Then using mud as a cover material, 10% of the area coverage of the radiator resulted in an increase of about 2° C of the outlet temperature of the radiator coolant (Singh, 2013)

This reference above from Singh shows that in the experiment performed, a debris of soil and mud the outlet temperature was increased even with just 10% coverage. This information is important as it shows that there a finding of increased temperature due to area coverage. Within this document are a number of graphs that show temperature difference from a heat exchanger with and without coverage from dirt. These illustrations provide a better look and analysis to what is actually happening to the heat exchanger.

As can be seen in figure 2 below taken from the document, as the area covered as a percentage increases so does the inlet and outlet temperatures. The coolant temperature at the inlet increases due to the outlet not being cold enough and then repassing through the engine again. This process slowly builds the inlet temperature to dangerous levels.

As this is unable to be tested in the experiments being run from this due to having a maximum heat



of 60 degrees Celsius, not a constant increase like you would see from an engine. The temperature in the testing apparatus TD1007 is controlled and therefore will not begin this cycle seen in the graph. However, for the experiment, the outlet temperature will be the main measuring device due to the inlet temperature being set and remaining stable.

Figure 2 – Temperature change taken from the Dirt analysis research document.

: Variation of temperature with the area of radiator covered with the mud

It was seen that the outlet temperature of the coolant from the radiator increased monotonically with the increases in the percentage area of the radiator covered. In both cases, at 80% coverage of the radiator the engine vibrated more than normal, and the idling was not stable. The engine stopped running after a short period of time. At 100% coverage the engine stopped running immediately after starting. This phenomenon was expected because as the effective transfer area of the radiator is reduced, less heat is taken out and thereby affecting the temperature of the coolant and the capability of the engine working was effected. (Singh, 2013)

From this short paragraph the effect on the engine can be seen as drastic, engine protection is a system in place to stop overheating in situations such as this. When applying this to the real world and testing in this experiment it can be seen that high levels of coverage have a dangerous effect on a car cooling system and operating conditions. If it was not for engine protection this engine would have experienced overheating results in serious damage if not fatal damage. While a 100% coverage may not be seen from a road car that constantly is moving unlike the test model in this example that remains stationary, debris/coverage material would have a chance to be shifted especially in wet/windy conditions. However, 80% coverage is a very possible situation especially from a car/vehicle that is experiencing off road conditions on a regular basis, for example a car owner who lives in a very rural area where off road tracks maybe driven on a daily basis.

Essentially starving the cross flow heat exchanger of its cross flow is taking away a major component of the system, through this research it is seen that mud and silt soil can take away this cross flow of cool air and stop the heat exchanger from working. However, from the experiments in this dissertation the effects of a much more common and instantaneous form of coverage will be tested. Knowing that on a full scale model the effects are emphasized from that of the testing apparatus TD1007, results achieved from the testing apparatus may be much less than that seen on a real model.

[4.2 Testing apparatus TD1007 booklet](#)

In this booklet there is information on not only how the apparatus works and how to set it up but also testing procedures and the science behind why such results would be obtained.

The information included in this booklet is crucial to the debris set up and the heat exchanger environment set up. Without this the testing would not be able to take place.

From this booklet there is testing procedures that can be trialled to see how the testing apparatus adjusts to different settings these can include; water temperature, air pressure/speed and water flow rate. For example, a testing procedure that gives a set input temperature, guides you to look at

the effect on the outlet temperature when the water flow rate is reduced by the same amount each time. From testing this in the second year it was found that a greater cooling effect was obtained, however the tank temp stayed quite high compared to that of a high flow rate that cooled the tank quicker even with an increased temperature of the outlet. This was due to more of the overall water being in contact with the cooling source/surface.

There is also a VDAS system in place on the university's, this system allows a laptop to be connected to the testing apparatus, and recorded data obtained from the testing apparatus to be relayed onto the laptop which must have the VDAS system installed on it. In this experiment for this dissertation the VDAS system is not needed as simple recordings are all that is needed. Looking at the temperature changes after a set period of time.

The use and possession of this booklet is very valuable to the experiments and adjusting set parameters, giving plenty of information on design and maintenance of the testing apparatus.

[4.3 The theoretical and experimental investigation of the heat transfer process of an automobile radiator.](#)

The heat exchanger was placed very close to the main sources of heat being the engine and exhaust, the added heat to the cooling system. This raised the temperature of the ambient air. Additional reasons for the differences between experimental and theoretical, is that the tubes going to and from the heat exchanger were providing heat transfer and cooling the system. (Matthew Carl et al., 2012)

This research paper looking at how the real life set up compares to the mathematical models is very useful and understandable when mentioning how the simulated set up is tested while being close to the engine and exhaust. Again, following the abstract of information above, when the car is travelling air not only passes through the heat exchanger but also the rubber pipes coming from the engine, this aids in cooling as the pipes disperse heat to the cool air flowing over them. This provides further information on the challenges faced when setting up a test simulation and that real world figures will always be different due to many contributing factors to the heat transfer taking place.

It seems that in both research papers there is a similarity in the set up. Being stationary and connected to an engine are the two biggest contributing factors to of then which display the results of a standard heat exchanger or that of one covered by debris such as mud or soil.

This research also provides more information on the upscaling of this investigation which is a route that could be taken with this dissertation's particular investigation.

5. Heat Exchangers

Heat exchangers or as they are more commonly known as radiators, are the most effective forms of heat transfer, offering maximum surface area to be exposed to the cooling or heating fluid. There are many different types and configurations of heat exchangers but for this investigation the focus will be on a water to air crossflow heat exchanger. This set up is very similar to what would be found in most automobiles on the road.

Heat exchangers by design are very complex with material that if laid out straight could reach, depending on the size of the heat exchanger, hundreds of meters, this is to maximise surface area and the number of pass overs. Pass overs being the number of times a tube carrying a specific flow rate of fluid passes over the cross flow from the other fluid. This then relates to the 32 and 16 tube HX's as they have 32 or 16 tubes exposed to the cross flow.

As shown in figure (3) below a Porsche 911, which has its radiators and condenser positioned in the side of the bumpers, a problem occurred when large quantities of debris were getting in through the gaps and depositing themselves in and around the main engine cooling HX and the aircon condenser. This was seen to influence the HX, but through this dissertation, a number can be put on just how much of an effect can be caused by debris.

In figure (4) below the 16-tube finned design HX that is in the TecQuipment apparatus kit, these fins aid in heat transfer as seen the Porsche's radiators also incorporate a finned design.

When looking at data from zero coverage of both HX's it would be interesting to see whether number of passes or finned design aids more in heat transfer.



Figure 3 – A design error by Porsche allowing debris to enter through bumper.



Figure 4 - 16 tube finned design heat exchanger designed by TecQuipment.

5.1 HX Material

When looking at different heat exchangers they are often made of different materials, many used to be made out of copper however these were too expensive for mass production and pretty much all major car manufactures have gone to aluminium to construct their heat exchangers. Different materials have different heat transfer coefficients, the higher the number the better the material is for heat transfer. However, there is usually a cost to improved heat transfer which is usually cost, followed by manufacturability.

Aluminium is chosen because it has a fairly good heat transfer coefficient and is relatively cheap. Along with being lightweight which is helpful when large heat exchangers are needed. Another move by the major car manufacturers was to replace the sides of the heat exchanger with plastic, this does not aid in the cooling effect but does bring costs down further again but can make them susceptible to splitting especially when overheating occurs and salt is present on the roads.

Therefore, cracking will occur in the outer surface layer which is in contact with calcium chloride when the outer layer is exceeding the tensile strain induced in the same layer. In such plastic parts, as a radiator tank or a water valve, there is an outer surface layer which is in contact with air and an internal surface layer which is in contact with water or a cooling liquid. (Wakabayashi, 1987)

5.2 HX Layout

The layout of car heat exchangers is normally water to air and cross flow, this so that the engine coolant liquid can be cooled effectively from air passing through the cars grill. This is the same set up as the testing apparatus TD1007. This is important as the whole experiment is relating back to a car engine cooling system, thus without the correct cooling system layout it would not be applicable.

However, there are many different types of layout such as concentric, plate, shell and tube to name just a few. Then there is flow configurations such as cross flow spoken about previously as well as parallel flow and counter flow. Choosing the correct configuration is vital for efficiency, for example a shell and tube heat exchanger would not be right for a car because it would not take advantage of the flowing air provided by the car's movement. Where as a plate/fin design on a motorbike works as there is less heat produced and air passing provides efficient cooling to the smaller engine. A few different types of heat exchangers can be seen in figure 5 below.

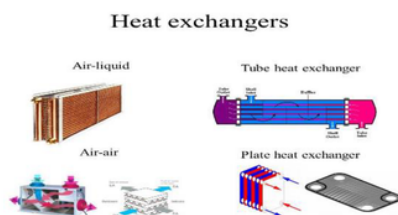


Figure 5 – Different types of heat exchangers.

5.3 HX Fluid

It is also important to provide the correct fluid to the cooling system in order to protect against boiling of the fluid. Using water is okay in systems that would never go over 100 degrees Celsius however in car cooling systems the engine is producing lots of heat and even though operating temp is best kept at 90 degrees C a minor issue can cause the fluid to raise above this temperature that is why coolant is used to help the water remain in liquid state even over 100 degrees C.

Coolant also protects the engine when not in use and ambient temperatures drop below 0 degrees C which is water freezing temperature, so having just water in the engine cooling system would mean freezing could take place and expand, cracking the engine.

5.4 HX Positioning

Positioning of heat exchangers in cars is another vital component, positioning in an area that will not experience much air flow will likely lead to overheating, whereas positioning too exposed on a road car could likely lead to damage from stones or debris. With a development in technology, smaller heat exchangers are now being used, in cars such as Hondas a small rectangle heat exchanger is orientated upright and to one side of the car. This can be seen in figure 6 below. Although positioning that cannot be helped is often aided by ducts which channel air flow to the radiator. When stationary fan help draw air through the heat exchanger to mimic air flow.

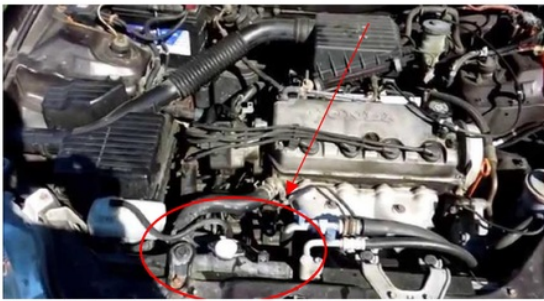


Figure 6 – Location of Honda civic small radiator.

6. Debris/Coverage

When using the term debris, the main objects being referred to are any type of rubbish or natural waste such as leaves and dirt which would get caught against the heat exchanger due to it being exposed. As mentioned previously in the Porsche 911 the side mounted heat exchangers would collect lots of dirt and leaves and deposit them on and around the heat exchanger reducing its efficiency. Although the different types of debris must be considered as a fairly thin leaf wouldn't cause as much blockage as a dense area of mud/dirt. Then there is manmade rubbish such as food wrappers and plastic bags, many food wrappers are foil which is a metal and therefore be much more insulating than a leaf. The one thing that natural waste has over manmade is that like in the Porsche 911 case it can build up over a long period of time and form together making it very hard for it to be dislodged from the area unlike manmade rubbish.

The main components in blockage/coverage is that they either reduce the crossflow over the heat exchanger from the cold side or they insulate the heat exchanger, both affect the job of the heat exchanger to remove heat from the coolant which is flowing around the engine of the vehicle.

Another factor to include in the theory is that many cars have air conditioning condensers fixed to the main HX this can reduce the effectiveness of the HX if the condenser is placed in front of the HX, some car manufactures prefer to place their condenser behind the HX so that the HX gets the coldest air and the condenser is going to factor less in hindering the efficiency of the HX.

6.1 Debris Access

When looking at preventative measures the way in which the debris was able to accumulate or become stuck upon the heat exchanger is of great importance. Many cars have front grills that allow cold and fast-moving air to crossflow over the HX. More and more modern cars are adopting a very large open grill with large gaps in the grill's mesh/net. This is great for cooling and possibly styling however it opens the HX up to much more debris and even worse damaging objects such as stones/rocks which can pierce a hole in the HX leading to either minute overheating with loss of coolant or complete overheating which can lead to engine failure. As seen in the Porsche's case an error in the design of HX placement and the grill design can lead to accumulation of debris on and around the HX. Not only can this bad design affect the efficiency of the HX but may also accelerate corrosion.

6.2 Debris Types

Looking at debris types in more detail, the two main categories in which debris will fall under are **Foreign objects debris** and **Insulating debris**. Foreign objects will include items such as leaves, crisp packets and other thin flat packets, any foreign bodies likely to be pushed up due to the force of the air against the heat exchanger. Insulating debris also can consist of leaves but along with dirt and soil and possibly animal faeces from animals such as birds and horses. This type of debris often needs to rely on a secondary surface to bind too in order to progress in growth over time, this can be things such as plastic shrouds or ducts that attach to the heat exchanger along with fan bolts that protrude through the heat exchanger.

Foreign object debris tends to be high impact over a short period as they can blown off or drop off when the car is stationary whereas **Insulating debris** will have a low impact building over a long period unless obtained by an off road journey. However, insulating debris can not only build up to be very damaging to the heat exchanger efficiency by also the structure as it can cause corrosion of the heat exchanger and/or fixings.

6.3 Other Affecting Factors

When considering the past sections and chapters on the components that can affect a heat exchangers performance there are a few more that can also hinder performance and efficiency. The first is damaged fins, where most road cars will have a fin and tube designed heat exchanger, the tiny fins that increase surface area can be easily broken by stones and debris. After a long time, corrosion will occur on these fins and a single touch could cause them to break.

Also the heat exchanger is part of a cooling system that relies on all components working together to provide efficient cooling to the engine, if a single component is not working at its supposed level, such as water pump, the whole cooling system will not perform as planned and therefore affecting the overall efficiency of the cooling system.

There are many factors that affect a heat exchanger ranging from design layout to air temperature passing over the cooling fins, but finding a optimum operating zone is possible to provide efficient cooling for the task in question, for example for most road cars that won't see the cooling system being pushed to its limits, a small cooling system and heat exchanger is often more than adequate.

6.4 Debris Simulation

Due to using the testing apparatus TD1007, there is good reason as to not being able to apply debris such as dirt and soil as well as a collection of leaves and man-made rubbish. Because of this the debris needs to be simulated. This will mean that area covered will be a lot easier to calculate and cleanliness will be kept in place. To simulate this debris, materials that reflect the debris the best are going to be most suitable. To do this simple thin and thick cardboard will be used, simply cut to size and positioned. For more insulating debris, clay can be used alone or in partnership with the cardboard. When describing thick and thin cardboard, the thin cardboard is just a bit thicker than paper and the thick cardboard consisting of two layers of standard cardboard with a corrugated piece in the middle. The air gap in the centre is going to cause more insulation it will slow the movement of air getting under and over the coverage much more than the thin cardboard.

The testing apparatus TD1007 allows for quick and easy access to the heat exchanger being used. This allows debris types to be changed and adjusted without the environment from the previous test changing too much. Attaching debris like cardboard can be done with small amounts of sticky tape to keep the cardboard from being blown away of changing orientation.

Debris like clay can be positioned in such a way to simulate that of dirt and soil that would build up in such a way in the frontal position where a grill opening is present or around the edges where plastic shrouds would aid in the build up of this insulating type of debris. Modelling clay will be used and positioned in the best simulating way possible, however it is difficult to simulate as the way insulating debris is deposited and accumulates on heat exchanger is difficult to predict and is different with every application in which it is found on heat exchangers.

As mentioned above to aid the clay in simulating natural insulating debris, it can be used in conjunction with the thin cardboard. This is because debris like mud and soil will often provide a thin layer over the heat exchanger and its fins before the majority of it settles. So varying sizes of thin cardboard can be used to see the effects of coverage that not only will be stopping airflow but also insulating the heat exchanger. When it comes to positioning of the clay, an approach that looks most like that seen from pictures of insulating debris will be applied. Even though this method is not very scientific, the size and mass of the clay used will be mentioned to provide the reader with more information about the simulated debris being applied to the heat exchanger being tested.

7. Coverage Continued

Below are pictures of the coverage displayed on the 16 tube heat exchanger just for reference, this section is just for the extra coverage pictures for illustrative purposes.



Figure 7 - Corrugated cardboard.

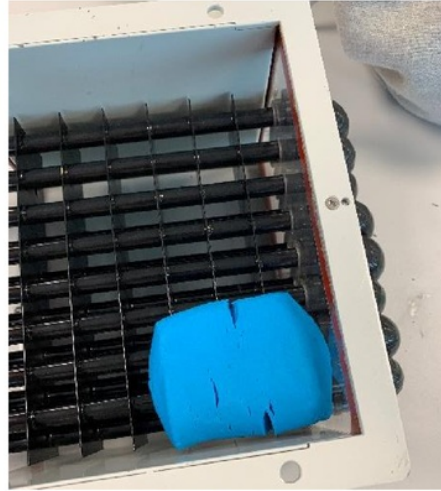


Figure 8 - Clay to simulate insulated derbis.

8. Air flow

When looking at the air flow within the testing apparatus, it is essential to note that the testing apparatus has seals around the placement of the heat exchanger so that air is forced over the heat exchanger and is not allowed to leak out from the heat exchanger placement area. When considering this in the debris testing, air flow must continue around the heat exchanger somehow as it is being forced there. Taking this into consideration when applying 100% coverage that there must be an area to relieve air pressure within the tunnel in which air flows towards and over the heat exchanger.

8.1 Permeability

Looking at the material used in testing, there is the capability on air leaking through the material, however during these experiments this can be ignored as the main area of airflow will be supplying the most amount of heat transfer while the coverage is in place.

8.2 Ambient air temperature

When considering that the greater the temperature difference the greater the heat transfer, the ambient air temperature plays its role. Even when no air is flowing over the heat exchanger there is heat transfer taking place and as mentioned in the first point, if testing took part on a cold day in the lab then that would also aid in the cooling of the heat exchanger. The ambient air temperature was 21°C during all tests carried out with only slight fluctuations due to doors opening and/or the heat given off the testing apparatus/heat exchanger.

9. Methodology

The methodology on this page will be applied to every test carried out. Strictly abiding to the information given will ensure the reliability of these tests.

The TecQuipment Heat exchanger has a maximum temperature of 60 degrees C, for the tests this maximum temperature will be used, this is so that small changes can be identified, and the hot temperature is as close to a car engine running at 90 degrees C as possible.

Wind speed will be constant throughout the testing along with air pressure. Further testing could use a wind speed measurement tool and the wind speed will be calculated in meters per second.

Once optimum flow rate is found this will be used for testing both uncovered and covered heat exchangers.

Running the TecQuipment HX is straight forward with simple on/off buttons for water pump, water heater and wind fan. The water heater is controlled via buttons to either increase or decrease water temperature.

Using cardboard or clay to simulate the coverage of debris. Cut to the shape of the desired percentage of coverage relating to the frontal area of the heat exchanger. Working up in small increments different percentiles of coverage will then be recorded along with the temperature of the water coming out of the HX ($T_{wh out}$). From this the efficiency can be calculated from referring to the temperature out of the system with zero coverage/debris. As seen below the black cardboard cut to size relating to 50% and 25% coverage. In these figures 9 and 10, thin cardboard is being used, in other testing thicker cardboard will be used. To simulate debris insulation material maybe be stuffed between the pipes reducing their capability to dissipate heat.

Times in between readings will be 2.5 minutes to assess and 5 minutes to record, but the main drive for a recording is when no change is seen after a long period of testing, for example is the temperature raises or decreases rapidly initially then is sat at the same temperature for a long period then it is safe to assume it is very unlikely that the temperature will change given a longer period due to the efficiency affected being controlled.

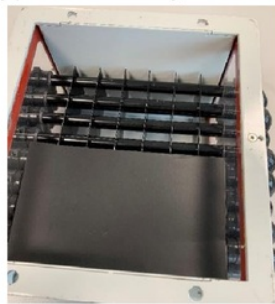


Figure 9 – 50% Coverage Displayed.



Figure 10 - 25% Coverage Displayed

10. Results

The results from each experiment will be documented below in excel spreadsheets and graphs to show how different percentage of coverage on the HX affects the efficiency. Figures will be displayed below and briefly spoken about before the discussion.

Initial testing was to see how the 32 tube heat exchanger works on its own and to establish base testing figures to then carry over into the debris covered testing.

Inlet temperature was set to 60 degrees Celsius, ambient air temperature 21°C.

Max Flow rate of the heat exchanger was 2.25 litres per minute, the plan was to start at this and work down to find the best suitable flow rate.

As seen in the table below, the best flow rate is 0.3 litres per minute, however this flow rate didn't seem suitable as it is quite slow and does not aid in cooling the main tank down quickly at all, therefore the flow rate 0.5 litres a minute was chosen to use carrying forward. This was interesting to see as it showed that when the hot side had more time in contact with the cold side of the cooling system the greater the heat transfer. However, when applying this knowledge to an engine, the longer the cold side has in contact with the cross-flow air on the heat exchanger the longer the hot side is receiving heat from the engine.

Coverage	0%
Flow rate L/min	Temp out C°
2.25	56
2	56
1.5	54
1	51
0.5	43
0.3	42

10.1 50% Thin Coverage

Moving forward to the coverage testing, starting with the 50% coverage with thin cardboard. This affect was tested for 5 minutes, recorded in increments to track the temperature change.

There was seen to be a temperature increase, even though it was not drastic it still is an increase that could affect performance and longevity of the engine and cooling system. The increase took the temperature from 43 C° to 43.8 degrees C. An increase of 0.8 degrees C, and efficiency loss of 0.36%, reducing the overall to 99.64%

Table 1 - Zero coverage testing results.

10.2 25% Thin Coverage

When testing the 25% coverage, the same environment was created again with 0.5 L/minute, standard set air flow, 60°C inlet temperature and 5 minutes to let affects take place, this time an increase of 0.3°C was observed after 5 minutes. It is important to note that in both tests the rise in temperature came within the first 2.5 minutes and then stayed consistent, if ignoring rising and falling figures of 0.1°C

10.3 25% Thick Coverage

Progressing onto the corrugated cardboard at 25% coverage, the thickness change was obvious to see figure 7. Again, with the same parameters set of 60 degrees C, 0.5 L/minute and left for 5 minutes to allow changes to take place. An increase of 1.2 degrees C was observed, nearly a whole degree above that of the thin coverage of the same area.



Figure 11 - Thickness difference between cardboard.

Demonstrated in figure 11, the difference in thickness of thick and thin cardboard.

10.4 50% Thick Coverage

Testing of the 50% coverage of corrugated cardboard was expected to see a further increase in temperature and so it was. The largest increase so far at 1.8° C was observed. This time, an exact degree over that on the thin cardboard.

10.5 75% Thick coverage

Choosing the corrugated thick cardboard to progress to 75% testing as this was seen to have the greatest effect on the heat exchanger. A further increase which totalled to 3.5° C. This was most aggressive test so far causing a dramatic rise in outlet temperature before slowly settling to a steady rise.

10.6 100% Thick coverage

Now onto applying a 100% coverage, this was done by using two 50% pieces that would fit in over the heat exchanger but still allow air to travel over and under the heat exchanger allowing the testing apparatus to continue working properly. A large increase totalling 8.2° C was observed, this took the outlet temperature very close to the inlet temperature, reducing any cooling affect to a minimum.

10.7 Clay insulated coverage

To simulate the insulated coverage, it was decided that a 50% piece of corrugated cardboard would be used in conjunction with 224g of clay. See figure (12) below. Unfortunately, the affect seen by the clay was less than expected causing a total increase of 4.2° C. Increase of 2.4° C of that of 50% on its own.



Figure 12 - Clay used in conjunction with cardboard.

11. Discussion

In this section the results will be talked about, compared to other findings and opinions given. This section will provide a in depth view into what the results mean and how they shape the overall experiment. Ultimately seeing if the results match the thoughts given within the introduction and other relative chapters.

11.1 Thin Coverage

When looking at the results obtained from 50% coverage, it is easy to look at a 0.8° C and simply ignore it as a negligible increase in temperature. However, it must be remembered that this was a very thin piece of cardboard and the area at which the water was sheltered from cross flow is very small before upscaling to a full car radiator. This result has shown that even with a small opportunity to raise, the temperature has done so and gives reason to test at a larger scale. Gaining confidence that the results follow suit from the other experiments, such as the one on dirt analysis. It is most likely that given a larger scale the temperature increase would be larger and possibly more drastic and detrimental to the engine and engine cooling system. Following on from above with an identical argument that given a very small area to raise temperature at the outlet the 25% coverage has done so. Only this time the 25% coverage is a more realistic type of coverage that can be seen in the real world. Given that radiators are becoming increasingly smaller, a foil crisp/rubbish package could be a very similar scenario.

11.2 Thick coverage

Looking back on the results obtained from the thick corrugated cardboard, the results are much easier to see than that of the thin coverage due to the increase temperature being much more drastic. Very similar operations were carried out in the 50% and 25% of both thick and thin cardboard, however when the 75% coverage was tested a different increase in temperature was observed. In the lesser percentages of coverage, a gradual increase was seen but with the 75% and 100% the increase was quite sudden causing temperatures to increase rapidly. As the outlet temperature was getting closer to the inlet temperature things started to slow but still increasing by 0.1° C every 20 to 30 seconds.

The most dramatic test came from the 100% coverage as temperatures soared very quickly with little signs of stopping until it reached its 7° C increase. When considering that even though set inlet temperature was 60° C the pipes leading from the tank to the heat exchanger were also expelling heat, which meant the recorded temperature at the very inlet of the heat exchanger was hovering around 58° C, comparing that to the 51.2° C final result of the 100% coverage, meaning a heat loss of less than 7 degrees C. This sort of loss in a car cooling system could be catastrophic to the engine.

11.3 Insulated coverage

As mentioned above in results, it was expected that a greater effect would be seen by the clay. However, it was still promising to see that the clay did increase temperatures above what the 50% coverage would do on its own. A problem that was seen during testing of the insulated coverage was that to not cause damage to the heat exchanger, there was caution not to place the clay into parts that could not be accessed easily for removal. This meant the clay was wrapped around just the frontal tubes which could be why it didn't cause as much of an affect as anticipated. The clay was very warm on removal and perhaps given a longer period with possibly higher temperatures it would cause a greater increase than seen from this test.

11.4 Analysis

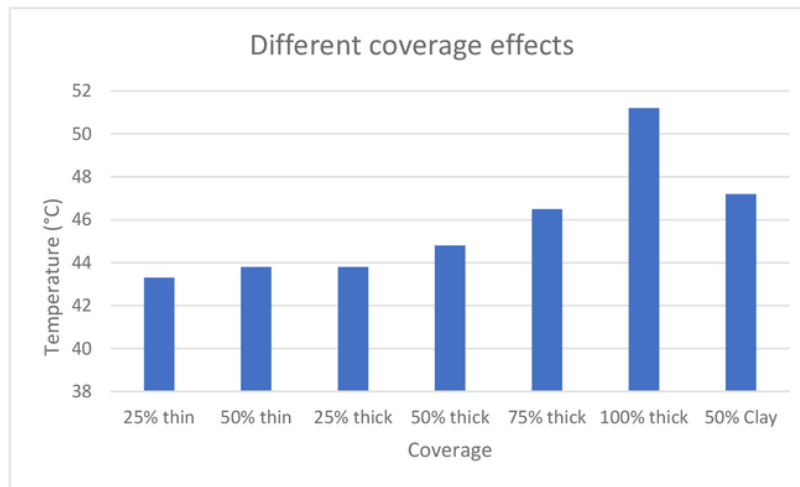


Figure 12, Comparison of coverage effects bar chart.

From the graph above the different coverages and their recorded temperatures can be seen, this graph goes to show not only an illustrative insight but also on how they compare against each other. From this the difference between 75% and 100% is a lot greater than that of the difference between 25% and 50%. This could be down to the fact that 100% coverage would not let any exposed surface from the heat exchanger become sufficient in cooling as there is no exposed surface area, apart from behind the coverage where the heat exchanger will dissipate heat into the moving and ambient air.

Comparing the 50% with and without the added insulation from the clay, the increase can be seen in this graph as quite significant. Take this and apply it to a better insulating material and the affect could be much greater. This also shows that insulating debris is factor that should be concerning when seen on a vehicle's heat exchanger.

11.5 Other notes

Looking back on the experiments and considering what would happen if certain parameters would have changed. These included, air temperature, air speed, purity of water, blockages and air turbulences. When looking at air temperature it would be interesting to test how much of an effect this would have on the heat transfer and perhaps even supplying a very cold dense air to the heat

exchanger. This could also be reversed by supplying a hotter air to simulate a warm climate in which many vehicles to operate daily in.

Again, supplying an air mass and a much greater flow rate or speed would also be an interesting to see if the faster or possibly slower air had a great impact on the heat transfer of the heat exchanger or not, as for the other points mentioned it would be harder to test these unlike air temperature which would require a heat source or cooling source and a thermometer, and air speed which would involve a faster fan and a device to measure air speed. However, the other points mentioned are worth noting as not every aspect of the testing is perfect and a hundred percent accurate.

12. Conclusion

In this section of the report a final conclusion will be drawn upon the outcome of the result and discussion. To help reach a final conclusion the discussion chapter will flow into this chapter in order to flow and understanding to take place. Leading on from this chapter will be the further work and changes chapter.

12.1 Thin coverage

As mentioned above in the discussion the thoughts of the debris effects are that even though a small increase was observed for both coverages over a series of tests. The increases are important because of the small size of the heat exchanger and the argument is that because there is little area or time for the raise in temperature to occur. Causing the 0.8° and 0.3° temperature rises in such a short area means the debris is damaging to the efficiency of the heat exchanger but at this stage not enough to cause over heating of the engine's cooling system.

12.2 Thick Coverage

When considering the thick coverage results, these results as mentioned in the discussion caused much more of an affect and would likely cause damage to a car engine cooling system if sustained for a long period of time for the 25% and 50% coverages. As for the 75% and 100% coverages, a build of debris to reach this level or a sudden application, would most likely re-enact the results seen from this testing and cause surges in temperatures which would either cause engine management to step in and cut out the engine or cause varying amounts of damage to the engine due to overheating.

12.3 Clay coverage

When looking back on using the clay as simulated insulation debris, there are factors that cannot be helped such as the clay having air pockets and not having the time or being as compact as soil/mud has. Considering that it would either be a sudden application of mud and soil from off roading which then settles on and around the heat exchanger causing a very insulating debris. Not to forget that decomposing soil and other natural debris that could be obtained from off roading, give off heat as the decompose adding more heat to the heat exchanger. Knowing this the clay does not stack up as well but is one of the most convenient methods of simulating debris. Other materials like house insulation materials such as mineral wool. This may have caused a greater increase in temperature and therefore simulated insulated debris better. The results obtained still indicated an increase even for the amount, material and way it was applied.

12.4 Overall conclusion

From discussing the results and concluding them, there is satisfaction in the results achieved and how they correspond to other research papers of a similar kind. The difference between this investigation and them is that this is a downscaled testing apparatus that is not trying to cool an engine which keeps supplying heat, with the TD1007 testing apparatus the heat coming in is kept at a constant. The results have shown from any coverage tested there has been an increase in outlet temperature, which when upscaled can cause an engine to run hot and there for a small increase over a long period of time can cause substantial damage to an engine and its cooling system.

The differences between a thin and thick cardboard which is only a few millimetres has made a dramatic difference, this most likely down to the corrugated cardboard containing a layer of air between the two edges which creates a good insulating barrier of air in which heat coming off the heat exchanger is trapped unlike the thin cardboard where it is not trapped by any layer of air, it is only having the air flow restricted.

It is important to remember that the conclusion drawn from these results are only estimating how they would look in a full size cooling system, but these conclusions come from research and background knowledge of the subject.

As seen from the discussion chapter 11.4, the difference caused by increased coverages can vary in its effect on temperatures, however as mentioned numerous times, the testing apparatus is constantly trying to raise temperature so an application that would could see a much greater effect on the heat exchanger and overall cooling system. For a small apparatus dealing with relatively low temperatures the results have been successful and correspond with other investigations. Keeping in mind that accessories of the cooling system such as the pipes and the heat exchanger itself were not being warmed by a nearby engine and the bends of the heat exchanger that are silicone were exposed and free of coverage. The temperatures rose and, in some cases, dramatically despite the lack of external heat being applied to the heat exchanger. This further goes to prove that upscaled models of this experiment with a full sized engine and cooling system could cause damaging levels of temperature rises.

However as mentioned previously the overall result of this investigation is a successful one that opens to more possibilities of testing and investigating.

13. Evaluation

When looking at how the testing procedures went, overall satisfaction was achieved through the means of precise and multiple tests. Using knowledge previously gained from using the testing apparatus TD1007 before in the second year of university studies, this provided a level confidence to use the testing apparatus with ease. Checking weather forecast to view atmospheric pressure for the area along with having a well working piece of equipment, this set up allowed the experiments to be carried out efficiently.

During most testing periods the lab was empty which meant there was always access to the things needed to carry out the experiment and the noise from the TD1007 wasn't disturbing other students.

Using a simple stopwatch to record times for the testing periods, the use of multiple tests ensured an average result was used to make sure anomaly results weren't calculated. The only things to report on were that the inlet temperature sometimes rose over the set temperature of 60 degrees C, another problem was securing the simulated debris to the heat exchanger making sure it didn't get blown off or trapped in position where it would be causing no debris simulating of blocking airflow. As previously mentioned, the fact that a set tank temperature of 60° C was not seen at the inlet due to heat transfer taking place in the tubes leading the to heat exchanger. This could not be helped, and it is a simulation of what happens on a real car cooling system as there are often long silicone pipes leading to and from the heat exchanger in which the heat transfer can take place to aid in cooling.

Allowing time for the tank to reach the inputted inlet temperature would sometimes take some time especially if it was a cold morning, however in this period, debris was being made or adjusted for that days testing.

Set up of the heat exchanger was done by a qualified technician to ensure the heat exchanger was connected properly and kept the working order of the TecQuipment TD1007 heat exchanger testing apparatus.

Application of the debris was done by detaching the main air flow tube from the fan side of the heat exchanger (before heat exchanger), sliding this tube backwards revealed the heat exchanger front and the simulated debris was able to be attached using masking tape. The change of heat exchanger was done similarly but with both tubes detached from the heat exchanger and then the water flow pipes.

Best efforts were in place to keep testing fair and accurate however 100 percent accuracy wasn't kept at all times, due to timing and disturbances.

Overall testing was successful with the only problems being disturbances and room/lab availability, if testing was to be done again the only thing changed would be more testing and perhaps try to improve consistency even though consistency was kept at a high level. Consistency was need for timing and recording of results and as mentioned this was maintained to a very high level.

14. Further Work/Changes

When considering changes to the experiments there are a few parameters and methods that could be added or fine-tuned. Parameters that were not available for monitoring when testing was taking place. These included wind speed and indoor atmospheric pressure. To calculate these a wind speed measuring device would be needed and for pressure an indoor barometer. At the time of testing the outside atmospheric temperature was recorded however this was not a true indication of the pressure within the room.

Looking at the testing part, there is always more testing that can be done to gain a more reliable result and/or accuracy of the result. Repeating tests multiple times could have been done on the same day if Lab time was available.

As mentioned previously, looking at different forms of insulating debris such as house insulation or even specific heat transfer insulation. As well as possibly obtaining a full size heat exchanger that carried natural insulating debris, applying this to a full size cooling system with engine attached to see what effect this naturally obtained debris would cause over the man made and attached debris.

Further work could be carried out looking at insulating types of debris. Simulating this with material such as clay to simulate a mud cluster that would insulate the heat exchanger and therefore starving it of cross flow air, providing a heated area.

As mentioned previously in this dissertation upscaling to either a bigger test apparatus or a set out engine with cooling system. With a real engine rig set up the results obtained would be very realistic to the real world and therefore be firmer evidence of the effects caused by debris.

Moving forward after these experiments, looking at upscaling would probably be the main next step other than looking at other avenues to experiment such as ducting or fin design.

Other changes to the overall report would be time management, allowing more time for writing and experiments to take place. Possibly using more types/simulations of debris to gain more data and results to report on. Overall satisfaction is high for this report and has provided a deeper level of knowledge and understanding of heat exchangers.

When looking in more depth, what can be done about the debris? Also, how can debris that can potentially damage an engine be stopped from accessing the heat exchanger or be removed from it?

Having answered some questions in this dissertation there will always be more questions to try and gain a deeper understanding of the goings on when debris becomes connected to a heat exchanger trying to cool an internal combustion engine.

As mentioned above about time management, a longer period of time to work on experiments and research would ultimately provide a deeper analysis, however there is only a certain amount that can be done with the TecQuipment TD1007 heat exchanger apparatus, and as mentioned above a really good application for this investigation would be upscale using a full size engine and cooling system. This could be done with a number of different engines available at the university that are all set up, however running them with debris on their heat exchangers is something that could be damaging at would have to be carefully planned out.

As mentioned in 11.5, looking at different parameters that could be measured with only a slight increase in testing equipment, this again would provide a further insight into the major affecting factors of a heat exchanger apart from the main one that is surface area.

15. References

Matthew Carl et al., D. G. (2012). The theoretical and experimental investigation of the heat transfer process of an automobile radiator. Beaumont.

Singh, Y. (2013, April). Dirt analysis on the performance of an engine cooling system. Cape Town .

Wakabayashi, H. (1987, December 8). Plastic Part Resistant To Deicing. United States.

15.1 Figure References

Writers work - WW

1 - WW

2- http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1021-447X2013000400006

3 - <http://www.revolution-porsche.co.uk/news/porsche-radiators>

4 – WW

5 - <https://slideplayer.com/slide/6613930/>

6- <https://www.youtube.com/watch?v=5uJNx2xm-yE>

7 - WW

8- WW

9 - WW

10 - WW

11 - WW

12 - WW

Table 1 - WW

16. Appendices

- Appendix A

'Dirt analysis on the performance of an engine cooling system'

A similar topic looking at another type of debris and the affect it caused, looked at in great detail.

- Appendix B

'The theoretical and experimental investigation of the heat transfer process of an automobile radiator.'

An investigation done on a heat exchanger working with no coverage/debris